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CLAY MODELING, HUMAN ENGINEERING AND AERODYNAMICS IN PASSENGER CAR BODY DESIGN

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by

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INTRODUCTION

The history of the American automobile began when Dureay's demonstrated his first car in 1893. Horse-carts and chariots were the main vehicles up through the 19th century, but men dreamt of self-propelled highway vehicles. The invention of the internal combustion engine, with its compact size as compared to that of the steam engine helped realize this dream.

These self-propelled automobiles were so novel to people that the engineers did not worry much about their shape and size. They mainly consisted of the engine and its components, wheels, and a seat on top with a steering device. Later, this seat was replaced by a carriage to accommodate more persons. These early cars were quite high mounted on the axles with open engine, that is, without any hood to cover the engine.

As the automobile industry developed, the engine was covered. A lamp was hung to aid enjoyment in night driving. According to Mr. Kaptur Jr., the 1904 Knox car was the first car with windscreens. The body of the car was much like that of a coach with entrance to the back seats from the rear of the car. This entrance was then modified and moved to the sides with the running boards to ease entrance and egress. The development of various accessories started the era of closed body cars. This resulted in combining the top, windshield, doors and basic body into a more complex unit.

The steering wheel replaced the tiller. The headlamps required a battery and generator. The self-starter required starter motors added to the electrical system of the car. Speedometers, shock absorbers and sliding transmission all added to the weight and size of the car, ultimately requiring a bigger engine. Such a closed car was introduced before the first world war.

Until World War I, the mechanical aspects of motor cars were given prime consideration. But as people took much interest, manufacturers paid attention to production and organizational problems. Later in the twenties the whims of people changed. They asked for convenience, comfort and good exterior appearance of the cars. In 1927, General Motors brought out the first La Salle which was completely designed by a professional stylist employed by the company.

The stylist, at first, was concerned with the art, color and the surface treatment of the car rather than the true integration of design and engineering point of view, though the cars looked marvelous and very attractive from the exterior. Ultimately, the stylist and the engineer were made to work together. The changing habits of the consumers spurred the team to further developments. The replacement of the beam axle by the front wheel suspension made it possible to move the engine forward between the wheels allowing the entire passenger compartment to move forward and eventually down between the front and rear wheels. Further, the trunk became part of the body shell and the spare tire moved inside. The headlights gradually became almost flush into the fender. The hood sheet metal moved out over the radiator and the fenders elongated, flattened and gradually became part of the body side. But this arrangement, in most of the present cars, has created a problem of getting in and out because of very low silhouette. The hump, in the passenger compartment to accommodate the drive shaft, occupied much interior space. The Corvair solved this problem by mounting the engine at the back. Introduction of facilities like air-conditioner reduced the space in the passenger compartment. At the same time the engine and transmission were moved forward as in the 1962 Buick and the hump was reduced. Chrysler introduced curved glass on their 1957 Imperial which made the doors even thinner and increased shoulder room.

Thus, the interior and exterior of the car has always been changing, and perhaps, will still keep changing to satisfy the desires of consumers.

PURPOSE

The automobile stylist is predominantly an artist. Yet in order to exercise his art and creative ingenuity he must have working knowledge of engineering and manufacturing problems, tooling costs, changing habits of customers and of the maximum utilization of storage space for the various components. In short the five elements of "Wheel of Design Creativity" as defined by General Motors Corporation, that a stylist must study are:

1. Market Analysis, a close study of people, their living habits and needs;
2. Production Economics, the concept of modern production facilities;
3. Human Engineering, to insure maximum safety, comfort and convenience for motorists;
4. Automobile Anatomy, the architectural scaffolding upon which the styling image is created, and,
5. Design Aesthetics, the final blending of all design elements into one unified, harmonious design.

Out of these varied fields of objectives of a stylist, we will confine ourselves in the first part of this report to the techniques of small and full scale clay modeling. The second phase of the report concerns the application of human engineering. This includes the anthropometric study of the human body which is important for the design of the driver's seat for comfortable driving. It also includes design of controls and displays to help reduce errors and hence, increase safe driving. The last section of the report deals with various aerodynamic forces acting on cars which, because of horsepower consumed in overcoming them, are important in the design of car bodies.

MODELING OF PASSENGER CARS

Sketches

It is about three years after the day the stylist starts putting his ideas on paper in two dimensional sketches that the first car rolls off the assembly line complete in every respect for use by customers. Even before this, a product planning group of the car manufacturers makes a market survey to gather public opinion and comments about the car models already on the market. This group tries to study the habits and likings of the custommers, their car budget limits and model preferences. The planning group also studies forecasts of the general economic conditions of the country and of some foreign markets and export promotion possibilities because some models might be popular in other countries.

Among other things that they decide is the overall dimensions of the car, space required for the engine compartment, price limitation, type of car such as luxury, compact or station wagon, etc.

After a decision is made and approved for production styling, the program for the future model advances to the "package" stage. At this point, the styling studios learn exact dimensions, weight, power and equipment requirements, and even the price of the car-to-be.

With this information on hand, the stylist begins his work. He starts with the study of trends in colors, furniture and fabric designs and other decoratives to be used in the car. Then, after deciding the type of car to be designed he goes on to paper and pencil. As he is naturally gifted with design creativity, he can express his ideas more effectively in two dimensions. These sketches, though rough, help create new ideas and designs. The most common way of presenting these ideas is to draw the perspective pictures of the car, both exterior and interior. The objective of this is to make as many approaches and come up with as many varied ideas as possible. As these begin to take shape the stylist also consults his chief who encourages certain ideas, gives suggestions, or disapproves ideas as being out of design limitations or technical feasibility. Many different sketches are made and displayed together on a screen. Similar attempts have been made by other stylists also and hung on a screen for final appraisal by the chief designer and his team members. Not only one basic design is selected, but several designs are selected which may be an individual or a team work effort. With these basic ideas of the car the styling staff goes ahead with more detailed studies. The stylist now draws the details to scale, in different colors, to give an impressive appearance. Again comes the screening and revising and selecting a few designs to be modeled in clay. Many times, before going on to the full-scale modeling in clay, small scale models are made, usually 1/5 full size. The main purpose of making a small scale model is to see the exterior appearance in a short time and with little effort. Even at this stage new suggestions can be anticipated from the product planning group who are in constant touch with market trends.

Clay Models

Small Scale Models. A small scale clay model can be started once the detailed drawings of the four views, front, side, end and top are ready. Wood or some other material can be used for the model. But clay is more advantageous as it is pliable enough to take any shape. It is cheap as it can be re-utilized and it is easy to work on and requires few instruments, such as scraper, hack saw blade, paddle, knife and semi-flexible scale.

Usually a grease base modeling clay is used, but not a water base or fire clay. To start the work of modeling an "armature", a sort of skeleton, is made of scrap wood, styrofoam or some other material. The armature reduces the amount of clay required and supports the clay. The armature size depends upon the overall dimensions of the car and the depth of grooves that might be a part of design. The armature is made in three or four pieces which will jointly resemble a very vague shape of the car.

The wooden working platform is about 20 inches long, 10 inches wide and 3/4 inch thick with 1/2 inch or 1 inch apart parallel lines drawn along its length and width. These lines are numbered to be referred to later on as station line identification.

Next a piece of wood, about 1/2 inch thick is nailed on the baseboard as the minimum distance of the body from the ground is 1/2 inch. The armature is then placed on this wooden piece. To make the armature removable from the baseboard, two identical holes, properly aligned, are drilled in the armature and the baseboard and then two wooden dowels are affixed in these holes of the working platform. Thus, the armature will fit over the dowels, and yet can be removed from the platform whenever desired. A number of small holes of about 1/4 inch in diameter and depth should be drilled on the armature at random to provide a proper footing for the clay mass.

Before applying the clay, a fast drying lacquer or shellac is used to seal the wooden armature. This prevents the porous wood from absorbing the grease in the modeling clay, making it difficult to form. Clay is then applied in fairly small pieces by hand to get general shape of the model car. A semiflexible metal ruler or a scraper is used in getting roughed in surfaces of the car. As work progresses the clay gets harder and better for sculpturing the details. One side of the car (longitudinal) is smoothened with the help of paddle and scraper. The window areas, high lines, door, hood openings, etc. are marked by a pocket knife.

When one side of the clay model is finished, station lines are marked across the model (up to the longitudinal centerline) corresponding to the station lines on the baseboard. These station lines can be drawn apart if the contour changes gradually or closer if the contour changes occur very abruptly.

The next step, very important in the modeling technique is called 'templating'. A very small groove is made along the station lines on the model. A stiff and thin cardboard serves as a template. A cardboard is cut, roughly, to the contour of the side of the car at one of the grooves. This cardboard is then inserted into the corresponding groove. This may require several trials before the cardboard can fit into the groove without leaving any gap between the cardboard edge and the surface of the model. On this cardboard the outline of the clay surface of the model is drawn by a pencil. Again the cardboard is cut precisely along the line to get the template ready. This template is given the same number as that of the corresponding station line on the baseboard for quick identification. Similarly, several other templates are prepared.

These templates serve the purpose of guides to finish the other side of the car. With little filling in or scouring out of excess clay a perfect symmetry can be obtained. Or, if any reservation is being made for another design with little changes, the clay on the other side will afford the opportunity to change the design and then compare the two. This is the advantage of working and comparing the designs in clay. The windows, hood, doors, trunk, etc., are again scribed by the pocket knife.

For coloring the models a special kind of paper called dia-noc paper is used. This paper comes in various colors and can easily be stuck on the clay by just moistening it, and is also very easy to remove. Hence, various color combinations can be tried on one model to select colors for the cars.

However, the procedure just described is not necessarily a unique one. Every stylist can make his model his own convenient way. Another procedure

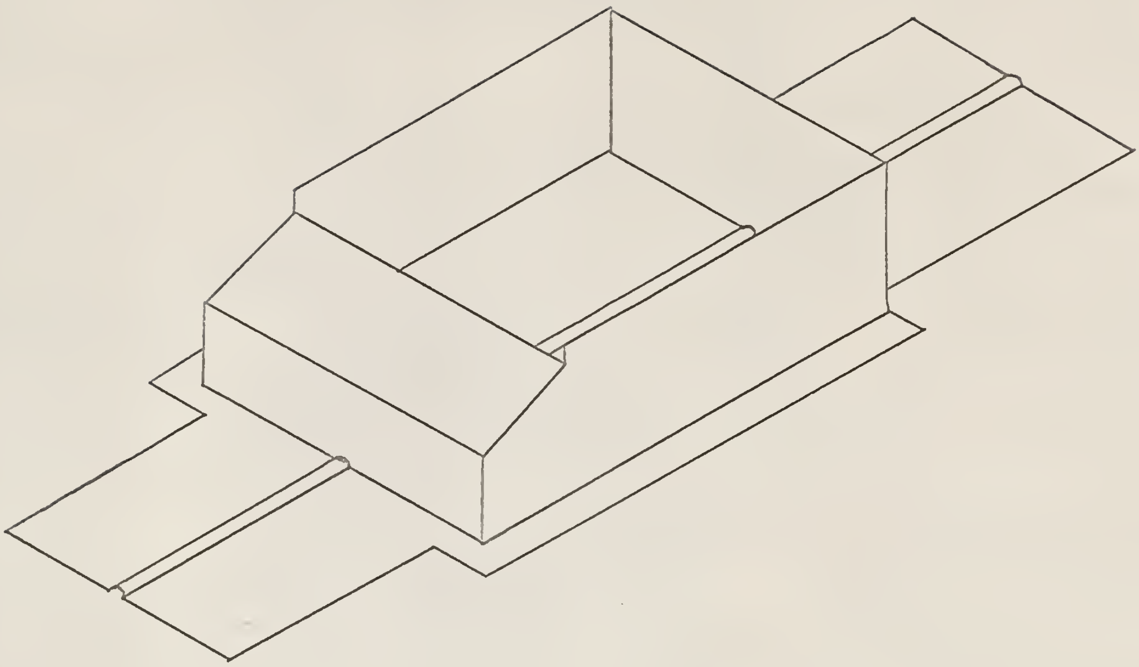


Fig. 1. The metal core.

with little changes, as described below, might help to get a rough idea about the interior of a car, particularly to visualize the footroom, head room, instrument panel, position of steering wheel, etc.

Once the detailed drawings of the exterior design are ready, an outline of the car, preferably the side view, is drawn. On this drawing approximate position of the seats, steering wheel and the operator is shown. When these are positioned an outline of the inner space is drawn. Similar drawings are made for the top and end views of the car. These other two views will give some idea of the thickness of the door as well as shoulder room for the passengers.

The model is a two piece model; that is, the top of the car can be separated at the windscreen level. However, the top still exactly fits over the body of the car.

The procedure is very similar to the one just described. The same baseboard is used with station lines as described. A core made of metal plates as shown in Fig. 1 serves as an armature. The size of this core represents the inner space decided previously. Then a full length metal base plate is cut to the width of the car. The four corners are cut off as shown in Fig. 1 to receive the wheels. As this base plate is going to serve as the floor of the car, it is corrugated in the center along the length. This serves two purposes: One, it stiffens the base plate to support the clay mass on it, and two, it resembles the hump inside the car to receive the drive shaft underneath.

Next, on this base plate the position of the core is marked. Within these marks two symmetrical holes are drilled. Corresponding holes are made on the baseboard, too, to receive the dowel pins for alignment of the base plate to the baseboard. The core is soldered on this base plate over the markings made previously. A wooden frame type mould is made which measures

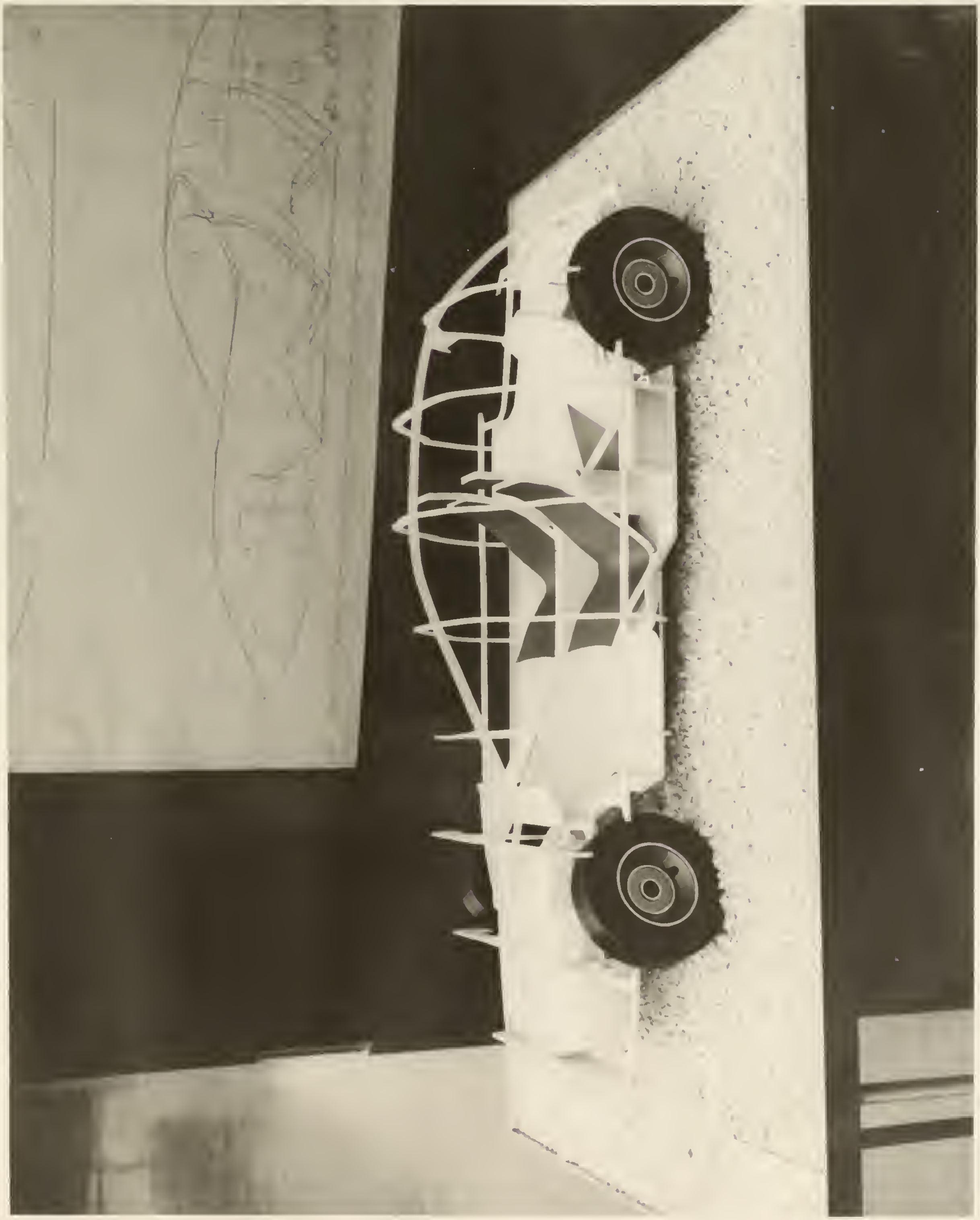
EXPLANATION OF PLATE I

Fig. 2. The drawing for determining location of the engine and the passenger compartments on the car body outline.

PLATE I

EXPLANATION OF PLATE II

Fig. 3. The drawing for determining location of the engine and the passenger compartments on the car body outline, as shown in the background.



slightly more than the overall length and width of the body of the car. The baseplate with core is fixed on the baseboard with dowel pins. The mould is placed in position and then clay is filled up in the remaining space. The mould is removed and the clay is worked with scraper and knife to get one side of the car finished as before. Then the templates help finish the other side perfectly.

The top is much simpler. A rectangular plate is cut to the size of the top with four thin strips at the four corners. The strips are then bent through 90° so as to rest the top on the body. The metal sheet is then covered with a thin layer of clay. The windscreen, side windows and the rear window can be substituted by plastic or some other material. The completed model can then be tried for different colored dia-noc paper as before. The core still represents the inner space. Scaled models of seats and steering wheels can be used to see the relative position of the driver's seat, the foot room, head room, etc.

Small scale clay models of the various designs will lead to the selection of the final design to be modeled on a full size scale.

Full Size Clay Models. The display of the various small scale models paves the way for approval of the design to be modeled on full scale.

The first step of this project is to prepare full size drawings of the car. The four views, front, side, end and top are drawn with every detail to exact dimensions. While a stylist works on these drawings, an engineer works out certain standards. He decides the location of the engine the propeller shaft, windscreen for proper visibility, trunk, etc. He does this either by drawing them on the same drawing where the car has just been outlined, or by pasting the templates of the engine, trunk and life size man as shown in Fig. 2 and Fig. 3. To provide proper leg room as recommended by the human engineer the engine or seats may have to be shifted fore or aft. This engine shifting will decide the hood line. Similarly, the head room that has been recommended for every possible headgearing will decide the position of the top and consequently the total height of the car. If necessary, the engineer is supposed to develop typical sections through critical areas to expose possible trouble spots in the design.

Full-size clay modeling now begins. The model is clayed over a wooden lattice-work frame or armature, which in turn, is built on the top of a heavy rigid aluminum structure. Clay is applied to the armature by hand, in small lumps at a time to get good adhesion to the adjacent clay.

The model is developed inside the confines of a so called styling bridge. This bridge is mainly a steel framework. A beam with graduated scales rests on two columns. The beam can be moved up and down and the columns, mounted on steel V-rollers, rolling on matting "V" tracks. The tracks run parallel to the side of the car. Thus, every point on the model can be perfectly located and can be duplicated on the opposite side, if required. Here it is not necessary to draw any station lines as the readings on the scaled tracks, columns and beam can easily be transferred to the other side. Slowly and steadily under the direction of the chief designer and stylist the clay takes the shape of the car. Templates are prepared for various curves of the car which later on help the interior designer to design his internal parts which will fit the surface.

Various other small round parts like tail light, head light, emblems etc., are made separately either by hand or on a potter's wheel. Bright chromium-plated parts are simulated by applying aluminium foil to the surfaces and burnishing the foil with a hardwood stick. Name plates, letterings etc. are carefully planned and designed, and later executed in plastic or metal to check out their appearance. With all details on, last comes coloring. The clay model is painted with a strippable paint or with the colored dia-noc paper. The finished clay model is then put forth to the management for their final approval.

Even at this stage any design change that the product planning group may suggest, to comply with the new trend in design, can be introduced. The change can be effected at least cost and time. This proves the greatest advantage of the clay models over the wood or plastic models.

By the time the model has been approved, the engineers have already started their preliminary preparations for the proto-type models. These proto-type models, made of fiber glass or plastic are complete in every respect. The exterior as well as interior design is being displayed as they would be in the actual car.

Human engineering experts work with design engineers and stylists on some human considerations for comfortable and safe driving.

APPLICATION OF HUMAN ENGINEERING

Men come in various sizes, tall, short, medium, thin and fat. But earlier car stylists and engineers did not take these variations into consideration. But now with about two cars per family in the United States this new factor has been included in the design of automobiles.

When extensive use of automobiles was realized, comfort was the first aim for distance driving and safety was the second to avoid accidents in fast traffic.

Research and development in the field of human engineering have made many changes in the designs of seats, controls and of displays for safe and comfortable driving. Because of the varying anthropometric data, the problem of standardization has become more complex; however, an attempt has been made to solve this problem by setting up the ranges recommended from the study of the anthropometry of a certain group of people. The mechanical designs of the controls and displays have been standardized in many cases by the study of human anatomy and man's response to various surroundings.

Design of Seat and Its Relative Position

The design of seats, workplace layout, reach and effort requirements, and spatial locations must be carefully controlled if fatigue, monotony, and errors are to be reduced and comfort, safety and efficiency are to be increased. Machines should be designed for the people who use them and for the environment in which both are expected to function. It follows that the efficient operation of machines, based on human perception and response, is dependent on the degree to which the machine has been designed to accommodate human physiological, structural, and functional factors. Therefore, now vehicle designers are expected to have developed operator-workspace criteria in accord with the ranges of anthropometric differences of automobile operators.

The test of this expectancy depends on getting data on the range of physical anthropometric differences known to exist in the vehicle-operator population and from these data deriving criteria useful in the evaluation of operator-workspace design. For this purpose are presented the data in Table 1 which are approximations of selected body measurements of the general driving population especially relevant to vehicle design. These data are not the results of an anthropometric survey of this population. They have been interpolated from selected anthropometric studies on various segments of the U.S. population, primarily U.S. Army, Navy and Air Force. It can be seen in the Table 1 that the data includes the average (50th percentile) as well as the 95th and 5th percentiles to give an indication of the upper and lower extremes of the group. If only averages were used in the design of a vehicle, it is likely that 50% or more of the group would find many of the arrangements unsatisfactory for their use. For example, a knee clearance just enough for the average person will be too small for the 50% who are above-average; and a control just reachable for the average operator will be too far away for the 50% who are below-average. Only 5% of the operators are smaller than the 5th percentile for any given dimension, and only 5% are larger than the 95th percentile. Hence, if the design can be made to accommodate these two extremes of the population, at least 90% of the operators should find the arrangements quite satisfactory.

The design recommendations that will be made in this report will be as an illustration of the application of human engineering based on the data of Table 1. There are chances that these data might vary for different groups of people at different places. Ideally, the goal of the designer should be to accommodate 100% of all the operators. Hence, the design recommendations can vary to a certain extent. Efforts should be made to accommodate more than 90% of the population wherever possible.

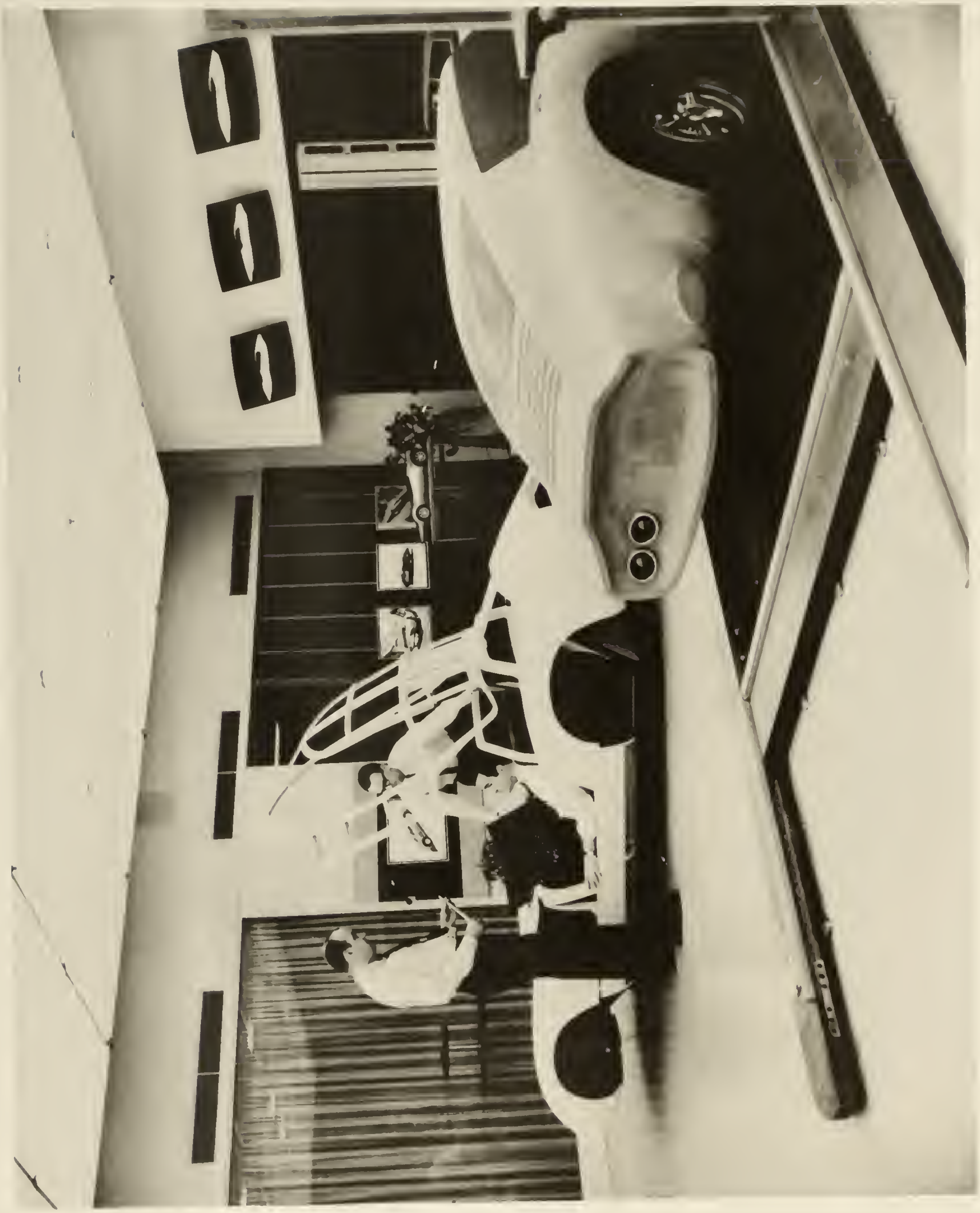
Human body measurements utilized in the design of the drivers workspace are of two distinct kinds, static and dynamic. The static body measurements are used in establishing clearances and allowances for problems of "fit" within a given space or between two or more structural items. For example, the various seat dimensions, and clearances above the driver's head or in front of his knees or abdomen are problems of static kind. For most of these dimensions, accommodating one end of the range in body size also, thereby, will accommodate all others below (or above) that size. For instance, the head room adequate for a 95th percentile operator will also be adequate for the other 94% smaller in size.

Dynamic human body measurements, on theother hand, describe the subject as a functioning, moving organism, as when operating the controls. Such measurements define an operator's ability to perform a given type or range of movements for the most efficient operation of the vehicle. Controls comfort-

EXPLANATION OF PLATE III

Fig. 4. The styrofoam mockup for the human engineering experimentation.

PLATE III



ably located for the 95th percentile operator in regard to arm or leg reach, may be, perhaps, too far removed for the 5th percentile operators to reach. And similarly, a foot pedal adequately placed for a 5th percentile operator, would possibly reduce the trunk-thigh angle considerably for a cramped 95th percentile operator and cause backache or interference with the shift lever. Hence, to provide adequate accommodation for a given size range of operators, adjustability is necessary at one end of the vehicle dimension, usually at the seat rather than the control. For this reason, specific recommendations based on dynamic human body measurements cannot be accepted universally, especially since there are numerous interrelationships within and between human body size and capabilities and the design and location of items in the cab area.

To solve this kind of design problem, where driving conditions depend more on different variables, an experimental approach can be the best remedy. There are two methods usually followed; one by experimenting on the operators in the car or its mockup and the other by using jointed manikins. If evaluation tests of a production model are being made the vehicle itself may be used to determine the degree of driver accommodation. But if the aim is to determine objective criteria for future design a mockup fully adjustable in seating, controls, instrumentation, and window areas is employed. The basic purpose is to design a vehicle suitable for all drivers from at least the 5th to 95th percentiles in body size. The best way of accomplishing this is by experimenting on a group of smaller drivers as shown in Fig. 4. The mockup is fully equipped with all the necessary adjustments. This experiment is then repeated for a group of larger drivers on the same mockup. The aim of experiment is to see how much adjustability is required for these two extremes of the group of operators with the controls and other instruments being at a fixed location.

Table 1. Human engineering body measurements of passenger-car drivers.

		Male Drivers Percentiles			Female Drivers Percentiles			Male and Female Drivers Combined (weighted average) Percentiles		
	Body Measurement[1]	5th	50th	95th	5th	50th	95th	5th	50th	95th
	Stature	64.1	68.4	72.6	59.5	63.4	67.3	62.3	66.4	70.5
	Weight (lb.)	131	166	216	105	136	190	121	154	206
A	Sitting Height	33.8	36.0	38.2	31.6	33.7	35.6	32.9	35.1	37.2
B	Eye Height	29.3	31.6	33.7	27.2	29.3	31.1	28.5	30.7	32.7
C	Shoulder Height	21.4	23.3	25.2	19.3	21.1	22.9	20.6	22.4	24.3
D	Elbow Height	7.7	9.3	10.9	8.2	9.4	10.9	7.9	9.3	10.4
E	Thigh Height[2]	4.8	5.7	6.8	4.9	5.8	6.7	4.8	5.7	6.8
F	Popliteal Height	15.5	16.9	18.1	13.9	15.2	16.2	14.9	16.2	17.3
G	Knee Height	19.8	21.6	23.5	17.9	19.5	20.8	19.0	20.8	22.4
H	Anterior Arm Reach	32.0	34.9	37.5	28.5	30.9	33.4	30.6	33.3	35.9
I	Abdomen Depth[2]	8.4	10.1	12.4	7.9	9.0	11.1	8.2	9.7	11.9
J	Buttock-Knee Length	21.6	23.5	25.5	20.7	22.4	24.0	21.2	23.1	24.9
K	Buttock Popliteal Length	17.4	18.9	20.8	16.8	18.2	20.0	17.2	18.6	20.5
L	Foot Length	9.6	10.4	11.3	8.8	9.6	10.2	9.3	10.1	10.9
M	Shoulder Breadth	16.4	17.7	19.4	14.3	15.6	17.5	15.6	16.9	18.6
N	Elbow Breadth	15.0	17.4	20.6	13.4	15.0	16.8	14.4	16.4	19.1
O	Seat Breadth	13.0	14.4	16.2	13.6	15.1	17.2	13.2	14.7	16.6
P	Foot Breadth	3.6	3.9	4.3	3.3	3.6	3.9	3.5	3.8	4.1

1 All dimensions are in inches except otherwise stated.
2 Tentative

Source: McFarland, Ross and Howard Stoudt. (14)

The second possible method is to use jointed manikins which accurately represent the body sizes of the 5th and 95th percentile drivers for this purpose. Such manikins can offer some idea of the driver's accommodation, but their use is not recommended exclusively as they can never be made to duplicate the biotechnical movements and posture of the human body. Although they may be used in mockups or as templates in scale drawings for a preliminary guide (Fig. 2 and 3), the degree of discomfort or difficulty of operation cannot be ascertained. Hence, the living manikins representing 5th and 95th percentiles are the best for this experiment. However, it is not always possible to get a human being exactly of either percentiles. Therefore, as an alternative, a person of height and weight very near to that of the 5th or 95th percentile can be put to the experiment. Since there exists a correlation between body measurements, the driving situation for this person can then be simulated for a person of 5th or 95th percentile. If enough subjects can be obtained (at least five for each group) a good idea of accommodation can be achieved, especially if it is observed how, and by how much, these subjects differ from the 5th or 95th percentile in the pertinent body dimensions.

Usually nude or lightly clothed body measurements are taken for the purposes of standardization. Accordingly the data in Table 1 is for a nude body. However as the type of clothing affects the static body measurements, an allowance must be made for this factor. It is very difficult to suggest a specific increment for clothes as it depends upon the geography, season and personal likings. In this report it will be assumed that the person is lightly clothed and the increments required are negligible.

With these anthropometric data of body measurements the relevant dimensions of the seats and controls can be recommended and have been designed. But the designs were not as good as they should have been. The design problem was difficult for several reasons: First, there is the necessity for keeping the legs and arms extended to reach pedals and steering wheels. Second, present styling makes cars and seats low which reduces the trunk-thigh angle creating backache complication on long distance driving. However, recent medical knowledge about causes of backache has helped improve the design of automobile seats.

Man is born with a straight lumbar spine. As he grows older and learns to walk a curve is developed in the lumbar region of the spine because the fixed sacrum in the pelvis cannot rotate enough to keep aligned with the lumbar spine. This curve is flattened when a person sits at right angle or stoops down to pick up something. This causes pressure on the soft discs making them bulge or protrude backward. This stretches the very sensitive covering ligament of the disc and causes lower back pain. When excessive pressure is applied, such as when stooping, the softer central portion of the disc is squeezed out into the spinal canal. This slipped disc may rupture the covering ligament and compress a nerve, causing pain in the hip or leg.

Several experimental X-rays were taken of people in different sitting positions. Two ways were found to improve these faulty seats; one, by increasing the angle of back rest with the horizontal and second, by providing lower lumbar support. It is observed that men do not sit at right angle in a "straight" chair. They slide forward to an angle of about 115°, and extend the legs moderately to about the same angle. This restores the lumbar curve considerably and is more comfortable without lumbar support. But if lumbar support could be provided, vertically curved and placed low enough to support the fourth and fifth vertebrae and discs, this angle could be reduced to about 105°.

Application of this medical knowledge has changed the design of seats with back rest at an angle of 105° with lumbar support and 115° without lumbar support. Further the length of the seat from the lumbar support should not be more than 16" for most people, particularly for women whose average height is 5 ft. 3 inches and the minimum relevant dimension of buttock-popliteal length for the 5th percentile female is 16.8 inches. This length permits the short person to make contact with the lower lumbar support without being crowded beneath the knees.

Free space beneath the knees is needed so the knees can be flexed and lowered, and it moves the pressure of the seat from the leg tendons back to the soft portion of thigh.

The seat should tilt up only 5^{o} just sufficient to prevent a person from sliding forward. Yet, it should not be so high that the pressure from the front of the seat on the back of the legs is uncomfortable. Besides, the sharp edge of the seat stresses the thigh muscles more. Hence, the edge of the seat is always curved like a "waterfall."

Other seat measurements and the relative position of the seat are usually recommended from the relevant body measurements. Seat height recommended is always less than the minimum, 5th percentile female operator, popliteal height to allow stretching of legs to reach pedals. Incidentally, this position becomes the upper limit of vertical seat adjustability, which is determined from the difference in eye height of the 5th and 95th percentile. This adjustment is generally in increments of 1/2 inch.

Breadth of bucket seat includes allowance for the shifting of position for the operator, while for side by side accommodation of three persons the seat breadth is sufficient to allow free movements.

The breadth of the back-rest is equal to the seat breadth. However, for the rear seats, where the back-rest breadth is less than that of the seat because of the protruding rear wheel fenders, the breadth should not be less than 54 inches. The minimum height of the back rest should be at least

Table 2. Recommendation for seat measurements and its relative position

Seat Measurements		Relevant Body Measurement	Percentile Male	Percentile Female	Recommendation[1]
Seat Length		Buttock-popliteal Length		5th	16.0
Seat Height		Popliteal Height	5th		14.0[2]
Seat Breadth	Bucket	Seat Breadth		95th	20.0
	For 3 persons	Seat Breadth		95th	58.0
Back-rest Height		Shoulder Height	5th	95th	22.0
Back-rest Breadth	Bucket	Shoulder Breadth	95th		20.0
	For 3 persons	Shoulder Breadth	95th		58.0
Seat-roof Distance		Sitting Height	95th		39.0
Seat-Steering Wheel Distance		Thigh Thickness[3]			7.5
Back-rest - Steering Wheel Distance		Abdomen Depth[3]			14.0[4]
Back-rest Dash board Distance		Buttock-knee Length	95th		28.0 or more
Pedal-Steering Wheel (or Shift Lever) Distance		Knee-Height	95th		25.0 or more
Vertical Seat Adjustability		Eye Height Difference	5th & 95th		4.5
Back and Forth Seat Adjustability		Buttock-leg Length Difference	5th & 95th		8.0

1 All measurements are in inches, based on Table 1, with a margin added for safety and comfort.
2 Measured at upper most position of vertical seat adjustability.
3 These measurements depend on fatness of a person and not on percentile. Hence, specific percentile group cannot be taken as reference.
4 Measured with the seat at the mid position of its back and forth adjustment.

12 inches to support the lumbar portion. However, in no case should it be more than the shoulder height, for it interferes with the free movement of the head. For this reason a head rest for the driver is not desirable. It can be provided for the other passengers.

With the modern trend in designing lower cars much economy of space is sought in providing head room. The vertical distance between the roof and the seat at the lowest position will be sufficient for any operators up to the 95th percentile, if it is enough for a 95th percentile male operator. Besides, the deflection of seat due to the operator's weight will add to the head room and allow free movement of head. However, the lowest position of the seat for the 95th percentile operator will make him elevate his knees because of the restricted forward space, and reduce trunk thigh angle to cause backache. The remedy is to provide back and forth adjustment of the seat. This adjustment depends on the difference of leg reach (most posterior point on buttocks to surface of the outstretched foot in sitting position) for the 5th and 95th percentile operator.

The distance between the seat and steering wheel should be sufficient to allow free movement of thighs while shifting the feet from one pedal to another. A reasonable allowance for this shifting added to thigh thickness will give this distance.

To avoid the identation of steering wheel on the abdomen the back-rest should be at a distance from the steering wheel, but it should not be far off, increasing the arm stretch to control the steering wheel.

The buttock-knee length of a tall person sitting with the seat at its rearmost position decides the distance between the back-rest and the dash board, whereas the knee height is the main criteria for the pedal to steering wheel or shift lever distance recommendations.

Table 2 shows the recommended measurements with the relevant percentile body measurement.

Design of Controls and Displays

The design of controls and displays is as important for safety as is the design of seats for comfortable driving. Recent researches in the field of human engineering have made achievements in standardizing the design of controls and displays which are mechanical. The main goal of standardization was to reduce the errors made in use of controls and displays which led to mishaps in the past.

Experiments on the controls indicated certain design aspects concerning:

1. Location of controls for ease and accuracy of reaching;
2. Direction of movement for greatest accuracy;
3. Amount of force to be exerted;
4. Rate of movement from point to point;
5. Speed and amount of rotary or wrist movement required in wheels or knobs;
6. Size and shape of controls;
7. Frequency of use; and
8. The degree to which the control performs a critical function.

Besides these considerations, there can be other aspects for a certain type of control. For example, the push-button type of control has one more consideration of 'feel' which makes us sure of its operation.

The design characteristics of the displays to respond to the controls designed from the above considerations are that they:

1. Can be read quickly and accurately;
2. Avoid ambiguity and possibility of reading errors;

3. Give information in terms of units required;

4. Are sensitive enough to note the change in values, or otherwise warn the operator of their inoperative condition, and;

5. Can be easily identified and distinguished from other instruments.

We shall see the designing of controls and displays of a passenger car namely, steering wheel, shift lever, foot pedals, milometer, temperature and fuel indicators etc., which are important from a functional point of view.

Steering-Wheel. The design of steering wheel should be such that it offers free rotational movement, that is, there should not be any friction or inertia force exerted by the wheel. Besides, a too sensitive wheel is not desirable for the operator is not likely to keep the steering wheel in perfectly steady position on straight track. Hence, initial play is necessary. For better control over the steering, a higher control to display ratio, known as C/D ratio, is desired. To increase this ratio either the number of control rotations per unit movement of the controlled object is increased, or the hand wheel diameter is increased. The minimum and maximum diameter of hand wheels is 7 inches and 21 inches respectively. To avoid outward or inward stretching of hands from the normal position, extended forward with right angle at elbows, the diameter of steering wheel can be recommended from the shoulder breadth. Looking to the range of shoulder breadth of 14.3 inches for the 5th percentile female operator to 19.4 inches for the 95th percentile male operator in Table 1, the steering wheel of 17 inches in diameter can be suggested.

The number of spokes on the steering wheel is usually two, three or four. What is important is that they do not obscure the indicators on the dash panel. In automatic cars it is advisable to have two spokes, for the gear indicator is usually mounted on the steering column.

When the hands are stretched forward to grasp the steering wheel, the forearms normally make an angle of about 45 degrees with horizontal. These hands are generally supported by the steering wheel. Hence, the steering wheels are mounted so that they make an angle of about 45 degrees with the horizontal.

The diameter of the steering wheel rim is generally recommended as 3/4 inch to 7/8 inch with contour moulding for proper grip. The steering column is sometimes brought up to the level of the outer rim. In this case the horn-ring in the center rubs with the forearm while turning the steering wheel. To avoid this interference the horn-ring is housed in the corresponding recess made in the spokes or, the spokes are bent to move the plane of the rim up parallel to that of the horn-ring.

Foot Pedals. Foot pedals or foot controls of an automobile can be operated with greater force in seated position. These pedals are either ankle-operated or leg-operated. The former are advisable for continuous use; e. g. for accelerators and the latter are for lesser use, but with greater force; e. g. for foot brakes and clutch pedals.

The angulation of the accelerator, being used continuously for a longer duration, should be about 110 to 115 degrees, which is the physiological resting position of the foot with the leg extended. This ankle-operated accelerator is best operated when it is hinged at the base of the heel. The optimum range of resistance for accelerator is 6½ - 9 lbs.

The recommended motion angle for accelerator is 10-12 degrees, which corresponds to the maximum travel of about 2 inches. However, care should be taken to see that the extended ankle angle does not increase the maximum possible of 115°.

The pedal brakes which require more force are usually leg-operated. The pedal is designed for maximum force of 200 lb., less than the maximum pressure exertable by the weakest operator. This force is effectively applied with knee-angle of 135 to 155°.

As the brake pedal has to support the weight of 7 lb. of average degree, the minimum resistance should be about 10 lbs.

The displacement for the brake pedal ranges from 4 to 7 inches and because of this large displacement, the brake pedal cannot be hinged at the heel base.

The clutch pedal, if at all provided, should also be similar to that of the brake pedal. But the force to be applied is not as great, hence, the resistance offered could be low when operated.

These pedals should be as wide as the foot of the highest percentile operator. From Table 1, a minimum width of 3½ inches can be set up. If it is still wider than this, it does not matter just so the pedals are properly spaced. The accelerator pedal, which is used continuously and hinged at the heel base, is pressed downward by the ball of the foot. Hence, the length of this pedal is recommended as long as the length of the foot, about 11 to 12 inches. The brake pedals, used intermittently, should be at least 3 inches long.

Pedal shape is not very important; it can be square, rectangular, circular, or oval as long as it is flat and affords a large enough area of contact with the shoe.

For brake pedals with which large forces are to be applied, a rubber padding is slipped over the pedal with a recessed heel section to prevent the foot from slipping off the pedal and assist the operator in locating the pedal by feel.

In no case should the pedal be placed under the steering column, for it may obstruct the foot in case of emergency and cause serious accidents.

Hand Controls. Apart from the steering wheel, different controls like shift lever, various knobs, switches and or push buttons on the dash panel, handles for window glasses and etc. are frequently operated by hand. Various designs for such controls have been suggested. Any such design can be recommended as long as it observes the general aspects stated earlier.

The shift lever usually does not require very high force to actuate it, but it should be stiff enough to avoid inadvertent actuation. If the shift lever is provided beneath the steering wheel, then it should not interfere with or rub the leg. The length of the lever is greater than the steering wheel radius so that it can be reached easily by just dropping the hand from the steering rim. This lever is a round lever of about 1/2 inch in cross-section. The lever is usually grabbed at the end, hence, this grip portion is of contour moulded to the shape of the hand. To avoid slipping off the hand the grip portion is usually diverging out to a greater diameter. The best position of the gear indicator will be on the steering column restricted to a height which will not obscure the indicator behind it on the dash panel. If the shift lever is on the side, then the lever should be long enough so the knob can be grabbed with the forehand at the elbow level. For instance, if the junction of the seat surface and the back rest is taken as the seat reference point (SRP) then the shift lever should come up to about 12 inches above SRP. With the arm making 30° of angle with the midplane of the body, the maximum arm reach for the 95th percentile is 28.7 inches, and the minimum for the 5th percentile is 23.5 inches from SRP. Hence, to avoid trunk movement while reaching for the shift lever it should be placed at about 20 inches from SRP.

The ignition key slot, and various knobs for the wipers, headlights, lighter and fuel pump if provided, should be placed near to the operator so that trunk movement is avoided as far as possible. The knobs for radio, air conditioner or heater may be at a distance, but not beyond the middle of the dashboard. These knobs are usually fingertip-operated. The general recommendations for grasping these control knobs are for the depth range to be from 1/2 inch to 1 inch and for the diameter range to be from 1/4 inch to 4 inches maximum. Because of space economy on the dash panel the diameter of knobs for proper accommodation can be recommended to be about 5/8 to 3/4 inches. To provide adequate gripping surface these knobs should be knurled or evenly serrated. The C/D ratio recommended is low as in the tuning knob of a radio.

These different knobs can be coded by using different sizes and shapes of knobs. However, in automobiles many times these knobs are of the same size and shape for the sake of symmetry and styling. In such cases each knob should be identified by inscribing the name plates, like LIGHTER, WIPER, etc., on the dash panel just above the corresponding knob.

The door crank should be at least 3¼ inches long to have proper grip by four fingers. It should always be designed so that, when turned upward, it will open the door. This avoids accidental opening of the door by resting a hand on the door crank. The door crank, window crank, and the vent-wind crank should be spaced on the door so as to avoid interference with each other or the arm-rest or the bottom edge of the dash panel.

The hand push-buttons operated by fingertips are used for quick operations -- for example, radio buttons and push buttons for automatic gear shifting. Buttons should have a minimum of 1/2 inches diameter and have either a concave or rough surface on top. This prevents the finger from slipping off. For the gear shifting push buttons a higher resistance is recommended. They can be placed on the left of the steering column on the dash panel and contoured for being operated by the left thumb. These gear buttons should be identified by proper coding to avoid error in operation.

Thus, many other controls which may be provided could be designed from the basic fundamentals of human engineering for equipment design.

Displays. The main displays in the automobiles are the various indicators like milometer, temperature gauge, fuel gauge, clock, directional signals, etc. The size and shape of these indicators are immaterial so long as the letters, indices and the pointer are designed from the standard recommendations.

The height to width ratio of letters should be one or more; generally recommended is three to two. These letters, indices and pointers should be clearly seen from the distance of at least 30 inches. For better illumination they should be covered with a radium compound. This will make them visible in darkness. In no case should the pointer be very long or so thick as to obscure any indices or letters. For this purpose, the letters are written away from the pointer and the indices are marked so that they are not completely obscured by the pointer but only the bottoms. To avoid crowding of letters, and hence the error of reading, only the major and intermediate indices are numbered. The indicators should be identified for the purpose they are to be used. They should be calibrated in the units required and in no case involve any mental conversion.

Windshield Area. The design of the windshield, mainly for the purpose of clear visibility, depends upon eye height, distance of the eye from the windshield, obstruction to vision and light transmission qualities of the windshield. The first three factors and the binocular field of the eyes help determine the height of the windshield. The width of the windshield usually complies with that of the roof.

To reduce glare during bright day light tinted glasses were used. But these tinted glasses reduced the light transparency to such an extent that for older people, whose retina sensitivity has reduced with age, serious safety problems were created. As a remedy to the two problems of glare and reduced visibility a clear windshield with a colored canopy at the top can be advised. This canopy will help reduce glare during bright day light. However, a very faintly tinted glass may still be used to avoid direct sun glare during early morning and late evening. Sun visors swiveling around one corner are also used. But they, being opaque, may in certain cases cause obstruction to vision.

Similarly tinted window glasses are not recommended, for the driver may have to look around through the windows at a road junction or while changing lanes.

Rear Vision Mirror. In today's fast and heavy traffic on the highways, rear vision mirror has become an important display for the operator while passing to right or left. This mirror helps in viewing cars to the rear, left and right. But this field of vision depends on the position of the mirror. For instance, a mirror placed on either fender of the car will not reflect any object on the opposite side near to the car.

An outside rear-view mirror can be placed anywhere from 25° off the line of sight to 75°. If this mirror is to be viewed for any long-time the operator has to turn his eyes. Automatically, this is followed by head turning and then the body turns so that the eyes are almost in the straight-ahead position with respect to the head. This causes only the insensitive retina of the eye to be perceiving the car ahead, and not to perceive it accurately, sometimes not noticing the slowing down of the car ahead and thus causing an accident.

Both the outside and inside rear vision mirror present a problem when they vibrate at frequencies that cause a severe reduction in perception and identification of the objects that are being looked at. A vibrating mirror at night gives confusing multiple images. Glare also causes nervous muscular tension and eventually reduces both forward and rear perception distances.

However, a variable reflectivity mirror allows the driver to choose any degree of glare reduction that he requires.

The simplest way to keep the operator aware of both the forward and the rearward traffic scene is to place the rear vision mirrors nearer the line of sight, at least within a 30° cone surrounding the line of sight. This serves many purposes. The presence of the mirrors in the near periphery creates an awareness of the body of the car itself, which brings about more rapid, smooth, accurate saccadic eye movements, for the end-point of eye fixation is already known and located. No searching correction eye movements are needed. The eye movements are accomplished quickly. When the operator is gazing down the road viewing the forward traffic events, any movement in the rear vision mirror would then be more apparent to him than if the mirror had been outside the 30° cone. No fixating of the mirror is required to view the traffic in the rear lane for it will be perceived by the sensitive part of the retina. With the same argument, there will be no trouble to view the forward lane traffic when the eyes are fixed on the mirror.

Another way of improving the rear vision is by providing a wider field of view which allows the driver to perceive more accurately the lateral motion of cars changing from lane to lane, for they are able to be perceived traversing the greater angular distances that are needed for their perception.

All the rear vision mirrors should be designed so that a portion of the auto body structure is visible for successful judging of distance and lateral placement.

To summarize, every motive of the stylist is studied in detail from the human engineering point of view by the body engineers and the experts in human engineering. We have mainly concentrated on the designing of controls, displays, and the seat for the driver, for they are supposed to be the most nearly perfect to reduce the possibility of error or inconvenience to drivers. The space for the passengers can be best utilized for their comfort. For instance, the basic design aspects for the passenger seat can be the same as those of the driver seat. But the question will be of its shape to fix it in between the two rear wheel fenders protruding inside the passenger compartment in such a way that it will provide enough leg room even when the driver's seat is in its rearmost position. Similarly, the arm rest can be provided on the doors or wheel fenders depending upon the latter's protrusion inside the passenger compartment.

The inner details decided from the experiments on the mockups are then incorporated with exterior design to make a proto-type model complete in every respect. This proto-type model is usually made of fibre-glass. It is equipped with all the components and is ready to be run on the proving ground. However, the high speed limitations on the freeways and highways have increased responsibilities of stylists and body engineers to see the effects of aerodynamic forces on the automobiles. The data on the various forces and the HP required, obtained from wind tunnel testing, are used to improve the future body design of cars.

AERODYNAMIC TESTING OF PASSENGER CARS

Clay models as well as fibre-glass models can be used for wind tunnel testing. Compared with fibreglass the clay surface is less stable during storage and shipment, and is easily damaged during tunnel installation and handling. It is an acceptable surface for the model at dynamic pressures up to 60 lb./ft.^{2} and tunnel temperatures up to 115° F. If the model experiences flutter of appreciable vibration during test, cracks may form and the clay may even break up and fly off. The repair and clean-up will consume much time. These troubles can be avoided in fibre-glass models. Besides, the clay cannot be finished to the extent of fibreglass finishing which almost complies with that of the actual car body. Hence, this may increase complexity in simulating the surface drag.

Engineers argue about the model scale in relation to wind tunnel size because of two main possibilities of errors. First, in the case of the full scale car moving through the air, the medium is essentially infinite. This is not true for a body in the artificial air stream of a wind tunnel, which represents a flow of finite dimensions. Second, in a closed working section (fixed boundary), the streamlines are compressed between model and wall. This results in an increase in drag. In an open working section, the stream-lines expand and the drag is decreased. Both errors depend on the model cross section area to tunnel working section. The smaller the model, the smaller the error. A thorough investigation has shown that for area ratios up to .04, the error is negligible or small. Beyond that, it increases rapidly. For this reason, a model cross section not greater than 4 percent of the tunnel working section is recommended. At the same time, a large model is also desirable because it provides adequate space to install test equipment and body surface accuracy, symmetry and details can be reproduced to achieve more significant and useful data. This leads to a conclusion that a wind tunnel section should be quite big enough to study the aerodynamic effects on the full scale fibreglass models for obtaining reasonably acceptable data.

The stylists and body engineers are concerned with the data of those aerodynamic elements which are in their control. They are:

1. Aerodynamic Drag.
2. Internal Flow Requirements
3. External Flow Patterns, and,
4. Aerodynamic Noise.

All these four elements require knowledge of pressure distribution and flow of air over and around the model. It is very difficult to study these two aspects quantitatively at various points on the model but the two quali-

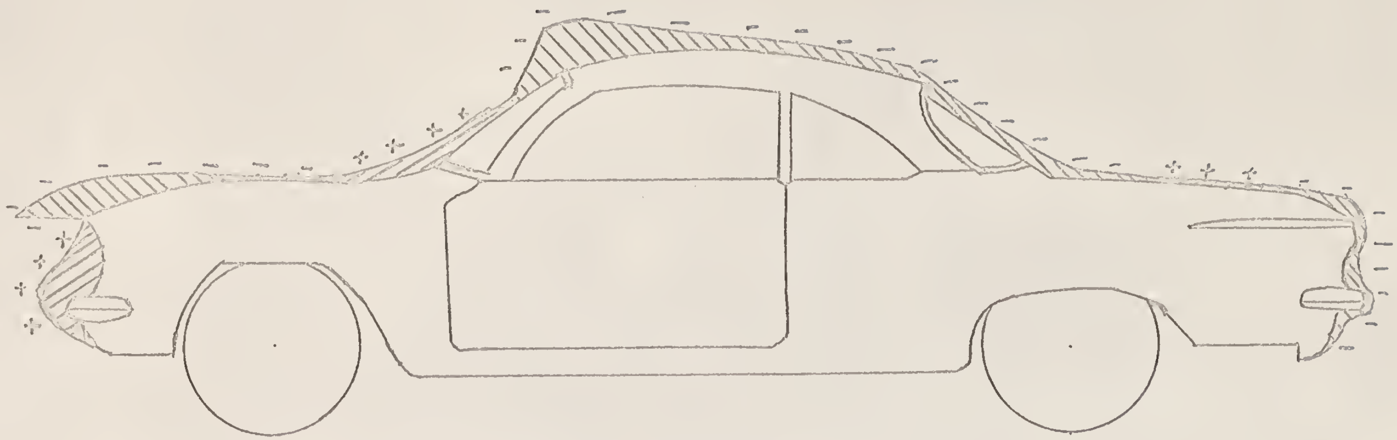


Fig. 5. Plot of static pressure coefficients measured along centerline of model.
(+ positive pressure)
(- negative pressure)

tative methods are quite useful and allow an insight into the flow conditions. These methods use visual body flow records made by body tuft photographs or by a suspension of lamp black in kerosene.

Figure 5 shows a simple plot of pressure distribution surveyed in the area of particular interest, the centerline of the model. The height of the line above the car is proportional to the static pressure co-efficients. Plus and minus signs indicate positive or negative pressure.

Aerodynamic Drag

The total power required to maintain a constant vehicle speed, called road-load horsepower, is the sum of all resistances or losses the vehicle experiences. It is the sum of aerodynamic horsepower and mechanical horsepower. Aerodynamic horsepower includes both internal and external aerodynamic losses. These losses are classified into five kinds of drag, namely:

1. Form Drag
2. Lift Drag
3. Surface Drag
4. Interference Drag
5. Internal Flow Drag

A study of aerodynamic drag for a typical passenger car showed the distribution as Form Drag 55%, Interference Drag 17%, Internal Flow Drag 12%, Surface Drag 9%, and Lift Drag 7%.

Form Drag. Form drag is directly affected by the basic shape of the vehicle. The specific contours of the car body determine how smoothly air passes over the body and to what extent the air flow is broken away or separated from it by abrupt changes in surface. Thus, the body shape determines the distribution of aerodynamic forces perpendicular to it. Summations of these forces in the direction of travel gives form drag.

The drag co-efficient, Cd, of the optimum shape, based upon its frontal area, is approximately 0.04, comprised of skin friction and pressure drag. One significant difference between this ideal shape and any actual automobile body is that the former is assumed to be in free air, whereas the automobile is supported by four wheels touching the ground. These wheels, even if assumed to be aerodynamically shielded, increase the Cd to about 0.15. This may be then taken as being close to the optimum realizable value for all automobile body shapes. Steep windshields, however, also cause disturbances to the flow of air, forming vortices well ahead on the hood. These vortices consume energy and result in high pressure at the base of the windshield and causes pressure drag as the flow passes off of the rear of the automobile. Thus, even with a well streamlined windshield the Cd will not be less than 0.15. However, acceptance of new design elements such as smooth, constantly - retarding fast-back bodies and relatively blunt rear end shapes may lead to passenger car shapes of lower form drag.

Lift Drag. Lift drag or induced drag is the result of any lift force which is generated by the moving vehicle. The magnitude of the lift force is primarily a function of the basic body shape.

A car body produces accelerated air flow and the corresponding low pressures on its upper surface, especially in such areas as the leading edge of the hood and roof, and the windshield corners. Aerodynamic lift results due to lower average pressures developed on the upper surface than on the underbody. The magnitude of this lift force and its distribution to the front and rear wheels is a function of the ground clearance, the contour of the body and underbody, and the angle of attack of the body to the air.

If the automobile can be operated at a considerably high level from the ground, then the underbody can also be streamlined to reduce the drag. But the fact that it should be operated just a few inches, about 6 in., above the ground level, the "ground effect" plays its role in increasing lift drag. The air underneath is not compressed but is moved out or sideways. This affects the air flow along the sides and over the top. If the underside curves upward at the rear very abruptly, the air below cannot fill in the larger space adequately and so air will be sucked under from the sides. Hence, the air at the top will be pulled over to the sides, and the overall effect of this air flow will be lift drag.

This lift drag becomes critical for light cars at high speeds. The car may lose its stability. A streamlined car will reduce lift drag.

Surface Drag. Surface drag is frictional resistance resulting from air passing tangentially along the car body.

Due to the viscosity of air a thin layer, called boundary layer is formed on the car body which causes frictional resistance. This surface drag depends on surface imperfections. A polished surface is desirable.

It is impossible to keep the surface completely smooth because of windshield frames, recessed windows, gaps, drip moldings, mismatch between parts, and sharp corners. These cause rapid build up of the boundary layer and frequently will cause airflow separation and more turbulence.

To reduce the surface drag air separation caused by sharp corners should be avoided as far as possible. The windshield should be well rounded into side windows and the top should curve down tangent to the windshield surface.

Interference Drag. Interference drag is caused by the many projections and protuberances that exist on the basic body. Exterior vehicle body projections such as a hood ornament, windshield wiper, radio aerial, rear view mirror, spotlight, accessory bug deflector, license plates, door handles, air scoop, roof pillars, rain gutters, exposed door hinges, and roof luggage rack all contribute to the total interference drag. The various mechanical components projecting from under the vehicle such as an engine pan, suspension arms, exhaust system, frame rail and rear suspension also contribute to the interference drag on the vehicle underbody. These elements interfere with basic air flow and cause major flow disturbances contributing drag to the vehicle far in excess of the drag they would produce if traveling separately at car speed.

As the air flows around or over an object it must speed up to cover the greater distance of the curved surface in the same time in which adjacent air flows along a straight path. Any object in the path of the curved air-flow will then have more wind resistance because of the relatively faster airflow.

Open wheels have more drag than covered ones. The interference occurs at the top of the tires. These portions of the wheels are moving forward twice as fast as the hubs and body so have four times as much drag as if the wheels were not rotating.

To minimize this drag all protrusions should be avoided as far as possible and the wheels should be covered. Installing a belly pan will eliminate interference of the underbody.

Internal Flow Drag. Internal flow drag is the sum of energy losses produced when air passes into, through, and out of all systems requiring or permitting air flow. Air flow is required through a vehicle as well as around it. The engine cooling flow which is the primary internal flow component, plus passenger ventilation flow and any internal flow required to cool brakes or other mechanical components, all contribute to internal flow drag. This drag is the result of momentum or energy losses experienced by the internal flow as a function of internal flow circuit configuration.

Proper pressure on both sides of the radiator and the temperature control of the air passing through the engine compartment and the air intake and exit for the passenger compartment will help reduce this drag.

Internal Flow Requirements

Selection of intake and exit areas for the provision of adequate engine-cooling air, additional mechanical component cooling air, and interior passenger heating and ventilation, as well as control and distribution of the heating and ventilating air flow inside the passenger compartment are the problems of aerodynamics for the body engineer. Static pressure distribution and velocity of air flow on the car body help in determing the locations for intake and exit of air flow.

It is possible to take in air for internal flow in either a high pressure - low velocity area such as the base of the windshield or at a low pressure - high velocity area such as the corner of the windshield. In the former case an intake can be flush with the hood; whereas in the latter case a scoop, which projects far enough from the surface to provide a sufficient forward facing opening outside the decelerated boundary layer, is necessary. This scoop can be located over the forward portions of the roof, of the hood, and of the fender tops. An inlet consisting of multiple scoops placed one behind the other performs poorly because the first scoop shields all those behind it. However, this is not so if they are provided on a high pressure surface and where the air velocity is not the dependent factor.

Velocity of air escaping from the windshield sideways near the vent window is very high. Therefore, these front windows are used effectively for bringing air into the passenger's compartment. Location of vent window pivots is important to direct air entering into the compartment. It is desirable to direct this air toward the lap area of the person sitting near that window with very little being diverted onto his face. This is accomplished by shifting the lower pivot slightly forward of the upper pivot so that the line joining the two pivots makes an angle of about 7° with the vertical and window can be opened through at least 120°.

The same vent window working as a scoop for intake of air also creates a low static pressure, which draws air out of the compartments when the vent window is set to take advantage of it. Exits are also provided at the rear of the compartment to gain advantage of sweeping air from the front to the rear of the body and to minimize the amount of noise reaching the front seat. Sometimes the blower fans are also used. The best of the alternatives should be used.

External Flow Patterns

The direction and velocity of air flow as it passes over a vehicle body is a function of the vehicle shape and the resultant high and low pressure areas that develop on the body surface. This flow is worth studying as it causes dirt deposit on the rear window and backlight and spoils the appearance of the car.

Deposit of dirt on outer body surfaces detracts from vehicle appearance and can affect safety if driver visibility is impaired. This can be eliminated by directing clean air flow to the body surface in question to divert the dirty air as it approaches. For instance, deposit of mud and dirt onto the back light of station wagons has been eliminated by top or side turning vanes which direct clean air into the backlight area and divert the contaminated air as it swirls up from under the bumper and approaches the glass.

Similarly, knowledge of external flow patterns is vital in placing the exhaust outlet to avoid its ingestion into the passenger compartment.

Aerodynamic Noise

Wind noise, as commonly known, is defined as the undesirable sounds caused by air velocity. This noise is caused by air pouring through small uncontrolled leaks in body sealing in a number of critical areas and is proportional to air velocity. The sustained high speeds possible on our modern expressways tend to accentuate this problem. This has emphasized the problem of aerodynamic noise in bodies which can make conversation difficult, mask radio output, and contribute to fatigue.

It is generally believed that wind noise is caused by a combination of aerodynamic shape and air leakage either into or out of the body. While this is true, objectionable wind noise can be eliminated by simply "sealing the door and window openings."

Occasionally, aerodynamic-induced outer body vibration is telegraphed to the passenger compartment mechanically because of a specific inner panel construction. Damping of panel or breaking the mechanical transmission circuit is required.

The most critical areas where noise is created are near the vent window and the front post, upper door frame and the rear of the front door, door sealing area at the belt line and the third post, and glass-to-door sealing along belt line or door sealing to roof rail or the central post. Noise created at all these four areas can be avoided by proper sealing. Other minor areas where noise is created are:

1. Grilles
2. Spacing between hood and grille.
3. Spaces in grille attachments.
4. Upper windshield mouldings.
5. Radio antenna.
6. Rain Gutter.
7. Rear-view mirrors.

These cause minor noise problems, being easily fixed at the source. But there is no standard test to find out leakages causing noise except to run the car down the road and then to determine carefully the noise sources.

By the time the aerodynamic testing of automobile prototype model is complete the production department is ready to go into production of cars.

SUMMARY

Design of a passenger car starts with its perspective sketches based on the recommendations made by the product planning group from their market analysis and on the wind tunnel testing on previous models. Only a few of the selected sketches are modeled in clay on a small scale to show the outer appearance. This helps in selecting one of the designs to be modeled on full scale. A full scale clay model can be equipped with every detail and tried for different color shades using dia-noc papers. This gives a complete picture of how the car will look. Clay is the best medium of model because it is pliable, cheap and easy to work with. This makes it possible to execute any last moment suggestion at least cost and time.

Knowledge of human engineering is equally important for the body engineers in designing the seats, controls and displays so as to avoid fatigue, monotony and errors for safe and comfortable driving. Anthropometric tables are useful in designing the seat and its relative position in the cab area. However, the design recommendations made from these tables cannot be standardized, for the data in such anthropometric tables represent a sample population of certain group of people, and not the driving population of the whole country. Hence, two such tables will likely vary in data.

Recent physiological research on backache due to distance driving has helped in designing the operator's seat. It recommends the back-rest angle of 105° with cushion and 115° without cushion, lumbar support, and seat length of 16 inch. Other seat dimensions are decided with the help of anthropometric tables. The aim of the anthropometric study is to see the variations in body measurements of the different percentile groups, and help determine the range of adjustability to accommodate at least the middle 90% of the driving population.

Design of controls and displays, which are more or less mechanical, are standardized from the human perception and response point of view. Recommendations for a particular control and display depend on its functional importance, degree of accuracy, ease of operation, and on minimum and maximum force required for its actuation. In short, design recommendations for controls and displays and seats made from the human engineering point of view, will reduce fatigue, monotony and errors to ensure safe and comfortable driving.

Wind tunnel testing of a passenger car is done for the evaluation of horse power consumption in overcoming the aerodynamic forces at various speeds, and the aerodynamic noise.

Form drag which depends on the shape of the car can be reduced by low frontal area. A smooth underpan to cover the underside of the car will reduce the ground effect and consequently lessen lift drag. Smooth surface and perfect matching of parts to avoid notches and grooves help reduce surface drag. Interference drag is caused by the protruding parts like bumpers, lights, mirrors, wheel openings, springs, suspension arms, steering rods, levers and other exposed parts. A flat smooth bellypan and proper designs of other protruding parts help reduce interference drag. Grilles, ducts, radiator, and engine should be investigated as they cause internal flow drag. Proper location of intake and outlet for ventilation will reduce internal flow drag. Summarizing all the improvements, a streamlined car body is desired to have minimum wind resistance. At the same time reduction in wind resistance increases the power at the wheels, requiring a more efficient braking system.

The air inlet for the passenger compartment can be located at the high pressure low velocity region or low pressure high velocity region. In the latter case a sort of scoop is required to take the air in.

Knowledge of external flow pattern is required to the extent of studying the dirt depositing on the car, and locating the exhaust outlet to avoid injestion in the passenger compartment.

And last, the aerodynamic noise created by high velocity air leakage can be avoided by proper matching of parts and sealing of openings.

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CLAY MODELING, HUMAN ENGINEERING AND AERODYNAMICS IN PASSENGER CAR BODY DESIGN

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AN ABSTRACT OF A MASTER'S REPORT

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The three important steps in the design of car bodies are, modeling, application of human engineering and the model aerodynamics.

The stylists make the preliminary sketches of car bodies based on the recommendations made by the product planning group. This is followed by small scale modeling to see the outside appearance of the car body.

Selected models are then modeled on full size with every detail, and tried for different colors with the strippable paints or dia-noc papers.

Clay medium for modeling is preferred to wood or any other medium for its pliability, cheapness and possibility of accomplishing last moment design changes at the least cost and time. The approved model is then modeled in fibreglass or hard plastic which exactly represents the actual car to be.

Anthropometric data or jointed manikins are used for designing the operator's seat and its relative position in the cab area. Recent research on lumbar spine flattening also helps in designing seats to restore the lumbar spine curve and avoid backache.

The controls such as steering wheel, shift lever, push buttons, etc. and the displays such as instrument panel, windshield, rear vision mirror, etc. are more or less mechanical devices which can be standardized. Proper selection of such controls and displays will avoid monotony and fatigue and will ensure safe and comfortable driving.

The aerodynamic testing of passenger cars is basically meant for the evaluation purposes. This test helps improve the shape of the car models to come and reduce aerodynamic drag. The study of pressure distribution of air flowing over the car body suggests the location of inlets and outlets of air for internal flow requirements. The leakage of high speed air causes aerodynamic noise.